ABSTRACT

The proposed study "*Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas*" is focused on the Paleozoic-age Ozark Plateau Aquifer System (OPAS) in south-central Kansas. PI's on this project are Saibal Bhattacharya and W. Lynn Watney, both with the Kansas Geological Survey (KGS) (University of Kansas), Lawrence, KS. OPAS is comprised of the thick and deeply buried Arbuckle Group saline aquifer and the overlying Mississippian carbonates that contain large oil and gas reservoirs. The Arbuckle Group consists of porous dolomitic carbonates with interbedded shaly aquitards. The OPAS in south-central Kansas is well suited for super-critical CO_2 sequestration in deep saline aquifers because of its depth (>3500 ft), thickness (>800 ft), and isolation from the shallow freshwater aquifers by regional caprock, the Chattanooga Shale (thickness $\approx$ 50 ft). Another caprock of lower Pennsylvanian shales overlie the Mississippian carbonates (thicknesses in 10's of ft). The OPAS in south-central Kansas is centrally located to multiple major point sources of CO_2 emissions. Demonstration of significant CO_2-EOR will motivate field operators to consider infrastructure buildup necessary to CO_2 injection in their depleted oil fields. This infrastructure can also be used for commercial scale CO_2 sequestration in the underlying Arbuckle Group saline aquifers.

Published estimates of CO_2 sequestration capacity in the Arbuckle Group in Kansas vary between 1.1 to 3.8 billion metric tones based on static CO_2 solubility in brine under *in situ* pressure and temperature. However, injected CO_2 and its solubility in brine triggers a dynamic *in situ* convection which aided by background aquifer velocity brings new unsaturated brine (from depth) to increase CO_2 sequestration. Significant and comparable tonnage of CO_2 can be additionally sequestered as residual gas saturation and some more by long-term mineralization in saline aquifers. In addition to sequestration capacity of the Arbuckle Group saline aquifer, the Mississippian Wellington Field is estimated to hold ~25 million metric tonnes of CO_2 thus underscoring the importance and timeliness of evaluating the sequestration potential of this large CO_2-sink in Kansas.

The proposed study, a collaboration between the KGS, Kansas State University, BEREXCO, INC., Bittersweet Energy, Inc. (Wichita, KS), will focus on the Wellington Field, Sumner County, Kansas, and integrate seismic, geologic, and engineering approaches to evaluate miscible CO_2-EOR and tertiary oil recovery potential in the Mississippian chat reservoir and CO_2 sequestration potential in the underlying Arbuckle Group saline aquifer. The proposed study will also develop a larger Arbuckle Group (saline) aquifer geomodel over a 17+-county area (centered on the Sedgwick Basin) in south-central Kansas and estimate regional CO_2 sequestration potential. The key scientific theme is to understand the geologic fundamentals behind the internal stratal architecture, structural deformation, and diagenesis and to evaluate their role on flow units, cap rock integrity, aquifer storage, and identification of reservoir compartments and barriers to flow. A 10 mi^2 3D seismic survey along with two new wells will be drilled (to the Precambrian basement) in the Wellington Field. The geophysical data including high resolution gravity/magnetics survey will be analyzed to characterize fracture/faults and compartments from the basement up through the overlying strata. One of the new wells will be cored from the Mississippian cap rock to the basement and special core analysis undertaken to determine facies-specific petrophysics. Modern logs (including CMR and FMI) will be run in both wells. High injectivity zones will be tested to determine aquifer/aquitard-specific geochemistry. Ultimately, reservoir simulation studies will be carried out in CMG-GEM to determine CO_2 injectivity in aquifers, tonnage of CO_2 sequestered in solution, residual gas saturation, and mineral precipitates. It will evaluate seal integrity in overcoming pressure increase upon injection, seal porosity changes due to geochemical reactions, and estimate CO_2 leakage as fraction of injection. Near- and long-term simulations will be carried out to quantify free phase CO_2, its distribution, and time for its dissipation, to understand plume growth, its area of influence and attenuation in presence of multiple aquitards and background aquifer flow, and movement in contact with fault zones. Detailed risk analysis studies will be conducted with FEHM simulator to estimate CO_2 leakage (injection fraction) as a result of cement degradation in existing wells. Successful completion of this "shovel ready" project will bring a confluence between commercial interests and sequestration viability leading to the establishment of a new "green" CO_2-sequestration industry in the Midwest.

Modeling CO_2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO_2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas

by

Kansas Geological Survey
KU Department of Geology

The University of Kansas
Lawrence, Kansas

in response to

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TABLE OF CONTENTS

PAGE

Project Overview

The proposed study will focus on the Wellington Field, with evaluation of the CO_2-EOR potential of its Mississippian chert ("chat") reservoir and the sequestration potential in the underlying Cambro-Ordovician Arbuckle Group saline aquifer.[1-3] A larger geomodel study of the Arbuckle Group saline aquifer will then be undertaken for a 17+-county area in south-central Kansas to evaluate regional CO_2 sequestration (Fig. 1). This study will demonstrate the integration of seismic, geologic, and engineering approaches to evaluate CO_2 sequestration potential.

1. Relevance of CO_2 sequestration in Kansas – The Ozark Plateau Aquifer System (OPAS) in south-central Kansas is an attractive CO_2 sequestration target. It is composed of Paleozoic carbonate and sandstone saline aquifers and interbedded shaly aquitards (Fig. 2) residing at depths sufficient to sequester supercritical CO_2. Estimates of CO_2 sequestration capacity in the Arbuckle Group (lower part of OPAS) vary between 1.1 to 3.8 billion metric tones,[4] representing over a third of estimated capacity for Kansas.[5] These conservative estimates are based solely on static CO_2 solubility in brine while dynamic *in situ* convection results in greater CO_2 solubility as heavier CO_2-saturated brine sinks resulting in new unsaturated brine (from deep) to come in contact with CO_2. Comparable volumes of CO_2 can be

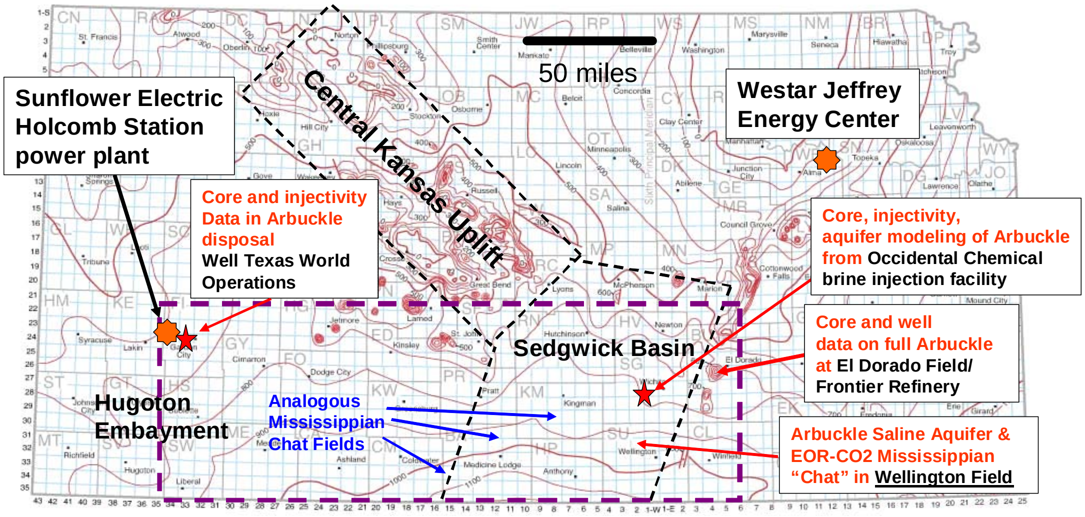

Figure 1. Isopach map of Arbuckle Group strata (base Simpson to Precambrian) from well data up to 1965. Contour interval 100 ft. From Cole[54] in Franseen.[1] Selected structural features include Hugoton Embayment, Sedgwick Basin and Central Kansas Uplift. Location of Wellington Field and large analogous Mississippian Chat fields are noted. Kansas' two largest coal-fired power plants, Jeffrey Energy Center and Sunflower Electric Holcomb Station, are identified.

sequestered as residual gas[6-10] and some by long-term mineralization.

Chat reservoirs in the Mississippian System (upper part of the OPAS) in a six-county area in south-central Kansas account for the majority of ~0..47 billion bbls and 3 trillion cubic feet of gas produced (KGS database). These fields are relatively deep, lack a strong water drive, and near depletion and are good candidates for miscible CO_2-based EOR, but this sequestration potential is minor compared to that of deeper saline aquifers. However, CO_2-EOR is an established process for incremental oil production and the infrastructure needed for its CO_2 injection can also be utilized for injection into deeper Arbuckle Group saline aquifers.

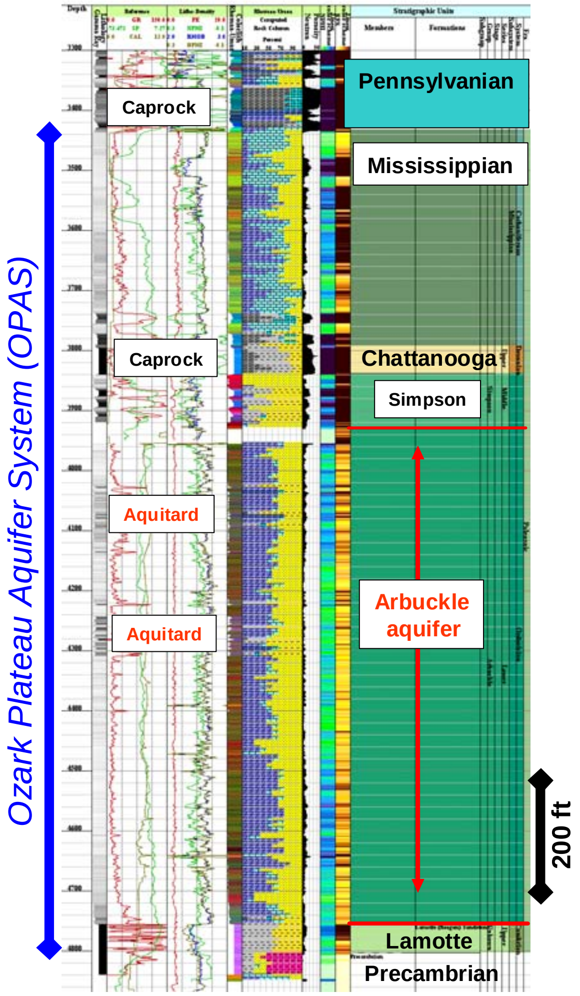

Figure 2 (left). Java-based color imaging well profile of deep cored Arbuckle injection well #10 at the Occidental Chemical brine injection site near Wichita. Left track is gamma ray (gray scale), well log traces (SP, GR, CAL & Pe, NØ, DØ), color lithology track from digital (LAS) logs, lithology percentage from logs, porosity (black filled), resistivity and porosity imaging bars, respectively. Far right columns depict stratigraphic classification and nomenclature with information retrieved "on-the-fly" from Oracle enterprise database.

2. Suitability of proposed project study area – Carr et al.[4] concluded that by virtue of its seal integrity, low flow rates, brine chemistry, mineralogy, and high injectivity, the Arbuckle Group has "excellent opportunity of large-scale CO_2 sequestration with hydrodynamic trapping, long isolation (>1000-yr) from the atmosphere, and protection of underground sources of drinking water supplies." An extensive Arbuckle brine geochemical database (3700 samples) is available at NatCarb.[11] However, stratigraphic details such as the number of flow-facies, their petrophysical properties, mineralogy, and water chemistry are poorly understood in the Arbuckle Group.

Depth (>3500 ft), thickness (>800 ft), and remoteness from freshwater (>100 mi to E) make the OPAS an appropriate study target. It is vertically isolated from shallow freshwater by the Mississippian-Devonian Chattanooga Shale, several Pennsylvanian shales (each 60+ ft), and ~500 ft of Permian evaporites across the western 80% of the study area.[12] These shales have maintained seal integrity over hydrocarbon accumulations for millions of years. Also, the Arbuckle Group has successfully served as a Class I and Class II disposal zone since the mid 1950's. Produced waters from oil and gas fields continue to be injected in it. As a result of Class I waste injection, three long cores (Arbuckle Group to basement) and one shorter Arbuckle core, well tests, and aquifer simulation results are available for the proposed study.

The Wellington Field (>20 MBO cum. prod.) currently produces 138 BPD of 42˚ API gravity oil with 10,000 BWDP reinjected. At present there are 47 producer and 15 injector wells (Fig. 3). A successful waterflood with secondary recovery in excess of 100% of primary makes this field a strong candidate for tertiary oil recovery. Reservoir pressure (1750 psi) and temperature (120˚ F) favor miscible CO_2 flooding. The Mississippian chat reservoir in Wellington Field (5120 acres, 20 ft thickness, 30% porosity) can hold ~25 million metric tonnes of CO_2 based on the MidCarb Sequestration Volume Calculator.[13] Its operator (BEREXCO) has partnered with the KGS to evaluate tertiary recovery in this field. Success in this endeavor will motivate BEREXCO to plan for CO_2 injection, thus providing an opportunity to validate the reservoir model

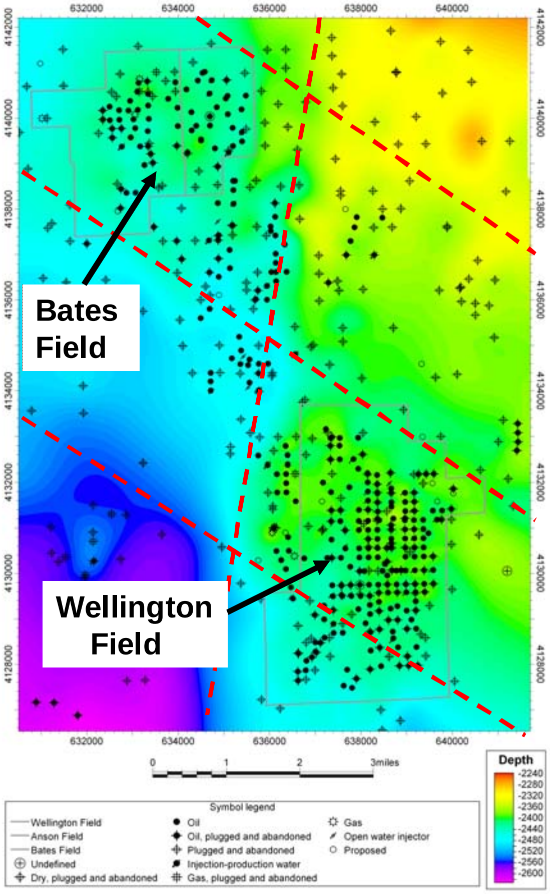

Figure 3. Configuration on top of the Mississippian (basal Pennsylvanian unconformity) in Wellington and Bates Field area. Fields are part of a Mississippian subcrop play with the chat reservoir preserved in what appears to be structural blocks bounded by NE- and NW-trending lineaments that conform to regional gravity and magnetic patterns.[23,55] Warmer colors represent higher elevation.

and simulation studies proposed herein. Local CO_2 sources include the Frontier Refinery at El Dorado (50 mi NE), the Westar coal-fired power plant at Saint Marys (120 mi NE), and the Sunflower power plant at Holcomb (140 mi W). Smaller CO_2 sources such as ethanol plants are also nearby.

3. Details of Proposed Project – The major elements of the proposed study focus on the Wellington field and include evaluation of the CO_2 sequestration potential in the a) Arbuckle Group saline aquifer-aquitard system, and b) overlying depleted Mississippian chat reservoir by miscible CO_2-EOR. Also, the Arbuckle Group saline aquifer will be modeled over a 17+ -county area in south-central Kansas to evaluate the regional CO_2 sequestration potential.

I) Characterization of Arbuckle Group saline aquifer and Mississippian Chat Reservoir at the Wellington Field – The OPAS at Wellington Field will be characterized using log and production data from existing and new wells, cores, and multi-sourced seismic and high-resolution gravity/magnetic surveys. A geomodel will be developed using Petrel (3D geocellular software). Two wells will be drilled to basement based on initial geomodeling. The first well will be cored from Mississippian cap rock to basement. A comprehensive suite of wireline logs (including FMI and CMR) will be run, and targeted zones will be drill-stem tested. The well will be cased, cemented, and perforated in high-injectivity intervals in the Arbuckle to retrieve brine samples for chemical analysis. Results will be used in the geomodel to site the second well. This well will not be cored, but it will be logged with suite comparable to that of the first well. **a) Seismic analysis**: ***i) 3D seismic survey*** – The survey will be calibrated with VSP and the dipole sonic log for accurate depth migration and thickness estimation of reflecting horizons. A 10-mi^2 vibroseis seismic survey will be acquired at higher-than-routine frequencies targeting the lower Paleozoics into the Precambrian basement allowing detailed analysis of the Arbuckle and mapping of basement structures. Thickness relationships among the various aquifers and caprock will be sought from the 3D seismic. Porosity mapping will be done using various seismic attributes. Geostatistical relationships will be established between surface 3D seismic attributes and borehole information to map porosities and lithofacies. Analysis of fractures will involve techniques such as separation of volumetric curvature attribute which has been used successfully to identify subtle fracture trends.[14-15] Curvature attributes have also been effective to establish complex reservoir compartments comprised of fractures, faults, and karst (DOE-KGS Cooperative Agreement No. DE-FC26-04NT15504). P-wave interferometry-based seismic attributes will also be used to increase fracture imaging capabilities. ***ii) 2D seismic survey*** – Compressional and shear wave velocities obtained from two cross 2-D lines will tie the two new wells and guide evaluation of crack-induced, shear wave anisotropy as a means of mapping the orientation of stress aligned fluid-filed cracks. Fracture domains that apparently affect fluid flow have been noted as part of the CO_2-EOR study in Vacuum Field, New Mexico.[15] ***iii) vertical seismic profiling*** – Multi-offset data and modeling would be utilized for correlations and optimizing processing flow and interpretations. ***iv) high resolution gravity and magnetic survey*** – High-resolution potential fields (gravity and magnetic) data collected at an 1/8 of a mile at the Wellington Field will seek to resolve the basement structure constrained by seismic and well data.[16-22] The basement essentially serves as a structure template that is activated through time as episodic tectonic stresses lead to reactivation.[23-32] **b) Routine and Special core analysis** – Three additional Arbuckle cores and their logs from near Wichita (22 mi N), El Dorado (50 mi NE), and near Garden City (200 mi W) will supplement the core to be drilled at the Wellington Field as part of proposed project. All four cores will be subject to routine and special analysis for porosity, permeability, vertical to horizontal permeability ratios, relative permeability, capillary pressure, and hysteresis end-points. Also, MMP (minimum miscibility pressures) and mechanical properties will be measured. **c) Water chemistry analysis** – Water samples from Mississippian and different Arbuckle strata (aquifers and aquitards) will be collected from the well drilled in the Wellington Field. For reservoir simulation purposes, geochemistry of these samples will be analyzed to determine reactive pathways and rates when the *in situ* water reacts with CO_2 and rock mineralogy and microbial effects on mineralizetion.[33] **d) Cap rock competency analysis –** Core samples will be examined by petrographic and geochemical tools to determine diagenesis, its environment(s) and history so that its influence in creation of impermeable sealing zones can be ascertained. Cathodoluminescence, SEM-BSE, and transmitted-light petrography will establish a cement stratigraphy and the extent and nature of fracture-fill sequences. Fluid-inclusion microthermometry, supplemented by Raman microprobe analysis, will provide temperatures, salinities, and compositions of fluids precipitating and recrystallizing mineral phases. UV epifluorescence microscopy will identify petroleum fluid inclusions so that oil migration can be placed into the diagenetic history. Growth zones fracture fills will be microsampled for stable isotopes (C, O, Sr) to help interpret the processes of dolomitization and cementation and to determine their timing and influence in cap rocks. **e) Hydrogeologic studies** – Information about aquifers and aquitards in the Arbuckle Group, their flow velocity and direction, will be gained from analyses and correlation of core and logs at the Wellington Field aquifer simulation studies related to nearby Arbuckle Class I injection wells. Results will allow assessment of the competence/continuity of low-permeability confining strata and regional hydraulic gradient. **f) Integrated geomodel development** – Detailed static geocellular models will be built for the Mississippian chat and Arbuckle Group reservoirs using Petrel software. One model will be built for the basement to surface for assessment of vertical and lateral seals and effects of faults. The static geologic models will include: structure and stratigraphy interpreted from seismic, potentials fields models, subsurface geology, and outcrop analog and petrophysical properties from wireline logs at appropriate scaling. The final numeric models will be constrained by sensitivity analyses performed during intermediate flow simulation. Zone-specific facies models will be built using sequential indicator simulation integrating vertical stacking patterns, facies proportions, vertical and horizontal variography, facies probability maps, and seismic attribute maps. Porosity and permeability models will be conditioned to the facies model using sequential Gaussian simulation and collocated cokriging using seismic-derived porosity attribute grids. Mechanical stratigraphic model will be based on facies and density measurements and borehole breakout measurements.

II) Evaluate CO_2 sequestration potential in Arbuckle Group saline aquifers and CO_2-EOR in Mississippian Chat Reservoir at the Wellington Field – CMG-GEM (Computer Modeling Group, Calgary) simulator will be used to simulate CO_2 sequestration potential of the Arbuckle saline aquifer, and the CO_2-EOR in Mississippian chat. This simulator is an adaptive-implicit multiphase multicomponent flow simulator with phase and chemical equilibrium and rate-dependent mineral dissolution/precipitation modules.[33] The previously developed multi-layer aquifer geomodel will be adapted to the

CMG-GEM simulator to include facies-specific relative permeability, hysteresis curves, and porosity-permeability trends, aquifer- and aquitard-specific water chemistry and pressure, reservoir fluid PVT, and location of nearby faults-fracture trends. The simulations will address many questions regarding the **Arbuckle Group saline aquifers –** i) How much CO_2 can be injected over 25 and 50 years under different scenarios? ii) What proportion of this CO_2 that will be sequestered in solution, residual gas saturation, and mineralization? iii) What is the time-frame for solution processes and mineralization[35] to be quantitatively significant over free-phase (supercritical) CO_2? iv) What is the optimal injection pressure so that cap rock yield points are not exceeded and capillarity leakages (fraction of injection) do not exceed the acceptable rate of 0.01%/yr[35]? iv) Will any free-phase CO_2 accumulate below the cap rock when CO_2 is injected in the deepest high permeability aquifer and as it travels through a series of aquifers and aquitards? v) Can CO_2 sequestration be enhanced by either simultaneous or sequential injection of brine (from top zone) and CO_2 injection (from bottom zone), vi) What porosity changes can occur due to mineralization, and location of maximum porosity change? The simulations will also address the following questions regarding the **Mississippian chat reservoir –** i) How much incremental oil recovery will occur in a typical 5-spot pattern? ii) What is the optimum injection pattern to maximize oil recovery? iii) How much CO_2 can be sequestered in solution, residual gas, and minerals? iv) What is the ratio of injected gas (CO_2) to incremental oil? Many aspects of **risk analysis** will also be addressed for both zones **–** i) Given the age and quality of cement, how many existing wells in Wellington Field will likely fail, what is the likely leakage[36] (as percent of injection) into shallow aquifers and to the surface? ii) Will the CO_2 plume migrate outside the risk assessment area, and over what time-frame? iii) What is the shape of the CO_2 plume and how does it change with time? iv) What are the effects of any sealing or transmitting faults[37-38] on plume migration and attenuation[39]?

III) Regional Evaluation of CO_2 Sequestration Potential in Arbuckle Group saline aquifers in 17+-counties around Wellington Field – The state of characterization of deep saline aquifers in Kansas, as is true for most areas, is not detailed enough for understanding storage, flow, and compositional changes that will be caused by CO_2 injection. Existing data are mostly averages of petrophysical and fluid properties, or gross estimates. To address this problem, all available wireline logs, cores, 3D seismic surveys, water analysis, DST, and well-test data pertaining to the OPAS will be inventoried for the 17+ -county area around the Wellington Field. Many companies are willing to share data in order to obtain a regional geological model. KGS has a large inventory of high-resolution aeromagnetic and gravity surveys, air photos, and satellite imagery from this area. These data will be analyzed to locate of major faults and fractures and to map thickness and porosity of the major aquifers and aquitards. Selected areas of the regional model will be simulated using coarse grids in CMG-GEM to determine regional CO_2 sequestration potential. These models will include facies-specific water chemistry and petrophysical data principally utilizing properties from the four cores cutting the entire Arbuckle Group. Primary and secondary oil production from major Mississippian chat reservoirs will be analyzed to indentify fields with high potential for CO_2-EOR using results obtained from Wellington Field simulation.

IV) Technology Transfer – The KGS has a long history of technology transfer. A huge amount of data will be collected, analyzed, and reported in this project and the main portal for its dissemination will be through a website hosted by the KGS and linked to NatCarb databases. Data can be downloadable in various formats, including spreadsheet and geospatial format with pertinent graphics utilizing Java web tools and applications. Lateral variability in stratigraphy will be conveyed through scalable well profiles and cross sections that display rock and fluid properties. An interactive GIS-based online mapping system, written at the KGS, will be modified to display, filter, and query cross sections and maps that characterize the OPAS. A best-practices manual for site characterization and selection will be developed. Core workshops, presentations at industry conferences, and peer-reviewed journal articles will also be product of the technology transfer.

Relevance and Outcomes/Impacts to Program Objectives

The proposed study will create and retain jobs, and is “shovel ready.” The selected Wellington Field has the potential to store at least 30 million tons of CO_2 and is close to several major point sources of CO_2 emission. Demonstration of significant potential for tertiary oil recovery and CO_2 sequestration will generate interest in the Kansas oil and gas industry to utilize their competencies in CO_2-EOR projects on existing assets and carbon sequestration projects in the Arbuckle saline aquifer underlying their oil fields. Project findings will be shared with the Southwest Regional Sequestration Partnership and NatCarb. The study will strive to develop best practices in characterization, modeling, and forecasting fate of sequestered CO_2 in aquifers and water-flooded depleted oil fields.

Roles of Participants

Project manager W. Lynn Watney has 33 years of experience in Kansas geology and is familiar with the OPAS. Saibal Bhattacharya, with 12 years petroleum experience in Kansas fields, will be the 2nd principal investigator. Bhattacharya has considerable experience reservoir simulation, has worked closely with Watney for 10+ years, and will conduct reservoir engineering and simulation studies. Other KGS co-investigators include: D. Newell, structure and diagenesis; J. Rush, Petrel geomodeling and data integration; R. Miller, seismic interpretation; J. Doveton, log petrophysics and core-log modeling; J. Xia, gravity-magnetic modeling and interpretation; and M. Sophocleous, aquifer modeling and well testing. Other KGS personnel include: J. Victorine, Java web applications; D. Laflen, core curation; and M. Killion, ESRI GIS; University of Kansas Geology Department will have four co-investigators: E. Franseen, stratigraphy and diagenesis; R. Goldstein, diagenesis and fluid inclusions; J. Roberts and D. Fowle, with microbial catalysis experiments.[40-42] From Kansas State University's Geology Department, S. Datta will conduct aquifer geochemistry[43-51] and A. Raef,[52] seismic analysis and modeling. Regional data collection will be subcontracted to Bittersweet Energy, Inc., under Tom Hansen. K. Cooper, engineer with 20 years experience on Arbuckle Class I disposal wells, will help in aquifer modeling. J. Lorenz will work with Hansen, Watney, and Newell to characterize fractures. Company engineers (D. Wreath and R. Koudele) with BEREXCO, Inc., owner operator of the Wellington Field, will supervise drilling, coring, logging, testing of two new wells, and seismic and gravity-magnetic acquisition. Hedke-Saenger Geosciences, Ltd., will manage seismic acquisition and initial interpretation.

Multiple Principal Investigators

W.L. Watney, the contact PI, will oversee geological analysis, regional geomodel construction, and data integration and synthesis. S. Bhattacharya, the 2nd PI, will oversee engineering studies, well testing, geomodel construction, simulation, and geochemical analysis.

Coordination and Management Plan

Watney and Bhattacharya will work closely together at the KGS and communicate with team members to assess progress using emails, biweekly conference calls, and meetings. Publications will be encouraged with authorship-order based on contribution. KU's intellectual property policy will be followed and conflicts resolved promptly and professionally.

STATEMENT OF PROJECT OBJECTIVES (SOPO) – "*Modeling CO2 Sequestration in Saline Aquifer and Depleted Oil Reservoir to Evaluate Regional CO2 Sequestration Potential of Ozark Plateau Aquifer System, South-Central Kansas*"

A. OBJECTIVES – Objective include 1) define heterogeneities of the Ozark Plateau Aquifer System, particularly, the deep, giant Arbuckle Group saline aquifer in south-central Kansas; 2) estimate CO_2 tonnage that can be safely sequestered in Arbuckle Group saline aquifer and in overlying depleted Mississippian chat oil field in the Wellington Field and regionally; 3) estimate potential of tertiary oil recovery from miscible CO_2-EOR; 4) quantify viable CO_2 injection rates into the saline aquifer; 4) evaluate seal integrity in Wellington Field and regionally; 5) establish tonnage of CO_2 present in free phase and sequestered respectively in solution, residual gas, and mineral precipitates over near- and long-term; 5) map fault/fracture distributions and orientation locally and regionally; 6) model CO_2 plume migration and attenuation over time and in presence of alternating aquifers/aquitards in Arbuckle Group and background aquifer flow; 7) inventory existing wells in Wellington and simulate their leakage potential due to cement degradation; 8) address risk management and best practices for saline aquifer CO_2 sequestration; and 9) transfer results to DOE, regulatory agencies, industry, and other interested parties. **Phase I (Year 1)** activities: 1) acquire and digitize well information for Ozark Plateau Aquifer System (OPAS) over 17+-counties; 2) assemble web-driven digital database, for interactive access, analysis and display; 3) develop regional correlation framework; 3) collect 3D seismic information and develop initial geomodel for the Wellington Field; 4) locate, drill, and evaluate Well #1 and determine if reservoir and aquifer pass quality. **Phase II (Year 2)** activities: 1) continue to collect regional data through year 2; 2) complete and test Well #1; 3) analyze core, tests, and fluid from Well #1; 4) locate, drill, and evaluate Well #2 and determine if the CO_2 injection rate in the aquifer and reservoir is acceptable. **Phase III (6 months into Year 3)** activities: 1) develop an integrated regional geomodel of Arbuckle Group; 2) refine geomodel at the Wellington Field; 3) simulate CO_2 sequestration potential in the Arbuckle Group aquifer at the Wellington Field; 4) simulate CO_2 sequestration potential of Mississippian Chat reservoir at the Wellington Field (**Is sequestration capacity sufficient?**). **Phase IV (last 6 mo. Year 3)** activities: 1) characterize possible leakage pathways; 2) conduct risk assessment for CO_2-EOR and CO_2 saline aquifer sequestration; 3) develop produced water and wellbore management plans; 4) coarse modeling of regional data on saline aquifer to estimate regional sequestration capacity; 5) establish regional source-sink relationships.

B. SCOPE OF WORK – Phase I. Watney and Bittersweet Energy will collect well and seismic data. KGS programmers will develop interactive web-tools for data upload, interrogation, and display. J. Rush and S. Bhattacharya will develop initial geomodels for Mississippian reservoir and Arbuckle Group aquifers in the Wellington Field and model CO_2 sequestration potential. BEREXCO will supervise collection of 3D seismic data followed by interpretation by Hedke-Saenger, Raef (KSU), Miller (KGS) and Nissen. Well #1 will be located and drilled. Bittersweet Energy and the KGS team will analyze data and report on CO_2 injection potential. **Phase II.** Watney and Bittersweet Energy will continue to collect regional data. BEREXCO will complete and test Well #1. Water and rock samples will be geochemically analysed by Goldstein, Fowle, Roberts, and Datta. The geomodel will be revised with new data. 2D shear wave data will be collected and integrated with 3D seismic to locate Well #2. **Phase III.** Bittersweet Energy, Watney, Newell, Doveton, Rush, Xia, Raef, Goldstein, and Franseen will develop integrated regional model. Bhattacharya will simulate regional CO_2 sequestration potential in Arbuckle Group aquifer. **Phase IV**. BEREXCO, Bittersweet, and Bhattacharya will characterize possible leakage pathways. Bhattacharya will conduct risk assessment, and address produced water and wellbore management with BEREXCO. Watney, Bhattacharya, and BEREXCO will establish regional source-sink relationships.

C. TASKS TO BE PERFORMED – **PHASE I** – **Task 1.0 – Project Management and Planning** – **Subtask 1.1. Review Project Management Plan** – Team will review project management plan at monthly meetings and revisions will be made as warranted. **Subtask 1.2. Report on activities** – Reports (quarterly, mid-year, annual, and final) will be written and submitted as required by the Program Management Plan. **Task 2: Characterize the Ozark Plateau Aquifer System (OPAS) over 17+ counties in south-central Kansas – Subtask 2.1. Acquire all available geologic, seismic, and engineering data for study area** – Obtain 3D seismic, gravity, magnetic, wireline log, core, DST, geo-report, brine analysis, production and well test data from the study area, 17+ -counties in south-central Kansas centered on the Sedgwick Basin where OPAS saline aquifers are deep and have high CO_2 sequestration potential,[4] to map the stratigraphic and areal extent of reservoirs and seals, from basement through the sealing strata (basal Pennsylvanian angular unconformity). **Subtask 2.2. Web-driven digital database assembly, for interactive access, graphic display, and analysis –** Existing KGS web tools will be customized for remote upload and data QC (quality control). The KGS online GIS map viewer will enable users to access logs, core data, well and field data, maps and cross-sections, and will be linked to DOE's NatCarb and Southwest Sequestration Partnership. The KGS Java-based web tools LAS File Viewer and Cross Section Web Tool will be extended to allow interactive color lithology imaging and cross-section display from digital logs (See Fig. 2). **Subtask 2.3. Develop regional correlation framework and integrated geomodel of the OPAS –** Structure, thickness, porosity, salinity, and pressures will be mapped and a sequence stratigraphic framework developed using core, well logs, and seismic data. Subsurface flow regimes, including the distribution, character, and barriers to flow (aquitards) and main hydrodynamic traps will be identified. Regional flow barriers, salt beds in the Lower Permian System, have been characterized over the western two-thirds of the study area.[12] Aquifer characterization will include salinity, permeability, and flow velocity and direction. Faults will be assessed as seals or transmitting features. Seismic data, magnetic and gravity data will be used to map fracture zones, estimate depth to basement, and highlight tectonic elements. Genetic and spatial associations[12] will be investigated to identify potential pathways for CO_2 migration. **Task 3: Develop a Geomodel of the Mississippian**

Chat and Arbuckle Group in Wellington Field – **Subtask 3.1. Assemble all available geologic and engineering** – Integrate all data (wireline log, primary and secondary production, core, DST, georeports, water analyses, production and well test) from BEREXCO, Inc. (operators of the Wellington Field) into a larger regional database. **Subtask 3.2. Collect and process 3D seismic survey, gravity, and magnetics data** – A 10 sq. mi^2 3D p-wave survey (3 component digital geophones with two 62,000 pound vibrators, 4 sweeps at 12 seconds each, and 5 seconds recording length) will be acquired over the Wellington Field and optimized to image the OPAS to basement. Processing will include Kircoff pre-stack time migration, frequency enhancement, and relative seismic inversion. Gravity and magnetic data will be collected at the seismic shot points with gravity data collected at 80 stations per sq. mile. **Subtask 3.3. Interpret 3D seismic survey, gravity, and magnetics data –** 3D seismic will include impedance inversion, spectral decomposition, and AVO characterization. Interpretations will include high-spatial frequency gravity anomalies caused by near-surface geology. In addition, gravity/magnetic data will be reduced to the pole simplifying interpretations and to a horizontal plane for more accurate interpretations.[18-19] Mapping structures, specifically faults, in the study area will be enhanced by maximum horizontal derivative and the second vertical derivative of gravity and magnetic data.[19-20] Borehole information will constrain the inversions. Gravity and magnetic data will be correlated to well and seismic data to better understand basement structural, compositional changes, and depth to basement elevation. Volumetric curvature attributes from the seismic data volume with fractional derivatives will be used to investigate multiple wavelengths of curvature. In additional to conventional analysis, quantitative relationships between various seismic formation characteristics will help build composite attributes sensitive to reservoir/aquifer properties. Multi-offset data and modeling will establish a fracture-imaging process for extracting pre-stack attributes. Also P-wave and S-wave velocity anisotropy will aid fracture detection and mapping. Geostatistical relationships will be used for mapping porosities and lithofacies based on seismic attributes and borehole information. **Subtask 3.4. Develop initial geomodel for the Wellington Field and locate Well #1** – Build fine-scale geomodels for Mississippian Chat reservoir and Arbuckle Group aquifer by integrating all data, upscale to flow-unit based multi-layered model, and locate Well #1 based of high probability of drilling thick Mississippian and Arbuckle sections. **Subtask 3.5. Drill, retrieve core, DST, and log Well #1 to basement** – Well #1 will be drilled to 3500' using conventional rotary methods. A core will then be taken from 3500' to basement at 5,100'. The interval includes the Mississippian and Arbuckle Group. DSTs will take pressures and fluid samples. A full log suite and vertical seismic profiles will be obtained. Production casing will be set for further selective testing. Cased-hole logs, including a cement bond log will be run. **PHASE II** – **Subtask 3.6. Analyze well log and obtain, process, and interpret VSP from Well #1** – Analysis of well logs and VSP from Well #1 will include: 1) calibration of log data with core measurements to predict porosity and permeability; 2) integration of compression, shear velocity, and anisotropy parameters determined from dipole sonic logs and seismic data; 3) estimation of rock mechanical properties from dipole sonic waveforms; 4) image analysis of FMI logs to determine location and orientation of natural fractures; 5) application of magnetic resonance imaging (ECS-MRI-CMR) to understand pore-body sizes and dual-porosity systems; 6) evaluation of formation invasion provided by the array induction tool so that flow-units can be identified; 7) application of resistivity and CMR log data to measure pore geometry. Other analysis will include facies-specific permeability and porosity predictions using numerical models, and stratigraphic correlations. Correlations will be extended to other wells with wireline logs. Dipole sonic measures of compressional and shear wave velocities will contribute to seismic interpretations. **Subtask 3.7. Sample water from select intervals** – Selected Arbuckle and Mississippian intervals will be tested after perforation by swabbing to recover fluid samples. **Subtask 3.8. Analyze Mississippian core from Well #1** – Mississippian cores will be analyzed in a manner following that of the lower OPAS units. The objective is to compare lithofacies and petrophysical properties in analogous chert reservoirs present to the west and southwest. **Subtask 3.9. Analyze Arbuckle core from Well #1** – Cores will be described in a fresh state for induced and natural fractures and discontinuities such as rubble zones, spin-offs, connections, etc. Slabbed and whole cores will be surveyed using natural light and ultraviolet photography. Lithofacies, fracture-fills, and mineralization will be sampled for petrography and geochemistry, and core analysis with the aim to develop facies-specific porosity-permeability trends, relative permeability, hysteresis end point saturations, capillary pressure and rock mechanical properties. **Subtask 3.10. Hydrogeologic studies of the Arbuckle aquifer –** Direction and rates of connate water flow will be based on in situ plume simulations completed for regulatory conformance of the two Class I disposal wells located about 20 and 50 mi from Wellington Field. Core and log analysis at Well #1 will be compared with data from the two Class I injection wells so that regional hydraulic gradient, and continuity and competence of local and regional aquitards will be gained. **Subtask 3.11. Analyze water samples from Well #1** – Geochemical investigations and monitoring of the CO_2-rock interaction will be used to infer formation of new carbonate minerals that can sequester CO_2 including microbial affects. Major reactive pathways and rates, equilibria, rate constant, and effects of surface area will be determined under in situ temperature, pressure, and salinity. **Subtask 3.12. Correlate log and core properties** – Spectral gamma-ray, array induction resistivity, neutron porosity, density, Pe, FMI, and MRI logs will be used to characterize mineralogy, mechanical properties, and pore systems. Permeability estimates are challenging in carbonates. Logs, cores, and DST will address these issues with the intent of developing robust predictions of permeability that are widely applicable to the Mid-continent. **Subtask 3.13. Examine diagenetic history of fracture fill –** Cores from the Mississippian and Arbuckle cap rocks will be analyzed for presence of fractures. Fractures, where present, will be analyzed for oil staining and cementation. Isotope analyses will be carried out on cap rocks and compared with that from Mississippian and Arbuckle Group aquifers to understand if seals had exposure to post-depositional fluids and if the cementation will prevent CO_2 leakage. Petrographic and fluid-inclusion studies will determine whether diagenetic minerals predate oil migration to evaluate seal competency. **Subtask 3.14. Collect, process, and interpret 2D shear wave (SHP) surve**y – Using sensitivity of shear wave velocity to rock matrix changes, two orthogonal 2-D shear wave profiles will be acquired focusing on reflectors within the Paleozoic and upper Precambrian section to provide vertical and horizontal velocity information for robust determination of slowness trends that will be geostatistically extrapolated around the site. **Subtask 3.15. Revise 3D seismic interpretation based on log, core, and 2D shear wave seismic survey** – Revisit approaches taken in Subtask 2.3 to reexamine interpretations of fracture/fault orientation. **Subtask 3.16. Update the geomodels of Mississippian and Arbuckle**

– All new data will be used to iteratively update the geomodels. Geomodels for the Mississippian and Arbuckle will be compared and common patterns discerned. **Subtask 3.17. Locate Well #2** – the siting will be based on expectations of drilling thick sections of Arbuckle Group and Mississippian chat with favorable properties. **Subtask 3.18. Drill and log Well #2 to basement and DST select intervals** – Well #2 will be drilled, DSTed, and logged to basement. It will be turned over to BEREXCO, Inc., operator of the field. **Subtask 3.19. Logs analysis of Well #2** – Log suite will be identical to Well #1 but without a VSP. Analysis of the wireline log will be conducted using correlations to core obtained in Well #1. **PHASE III** – **Subtask 3.20. Develop an integrated geomodel of Wellington Field** – An integrated geomodel, emphasizing characteristics of the Mississippian chat and the Arbuckle Group, will be built. **Task 4: Conduct Simulation to Evaluate CO_2 Sequestration Potential in Arbuckle Group Saline Aquifer (underlying the Wellington Field)** – The multi-layer aquifer geomodel will include aquifers/ aquitards and cap rock of the Arbuckle Group. Simulator input will include facies-specific relative permeability and hysteresis curves, porosity-permeability trends, aquifer/aquitard-specific water chemistry and pressure data, and location of faults-fracture trends. **Subtask 4.1. Estimate CO_2 sequestration potential of aquifer –** A simulation will be conducted to understand: optimal injection rates and best injection intervals, storage capacity of various trapping mechanisms (residual gas saturation, brine solution, and mineralization), reactions with the subsurface environment, effectiveness of cap rock in preventing leakage, size and fate of CO_2 plume, time frame over which CO_2 flux becomes negligible in subsurface. **Subtask 4.2. Evaluate long-term effectiveness of cap rock –** Quantify CO_2 accumulation and pressure increase under cap rock after free-phase CO_2 is injected in Arbuckle Group aquifers. Model mineral interactions between CO_2 and aquifer cap rock to evaluate cap rock porosity changes. **Subtask 4.3. Quantify CO_2 sequestered in brine solution –** Simulate CO_2 tonnage sequestered in brine under aquifer salinity, pressure, and temperature as a result of in situ convection currents, varying brine geochemistry with depth, and background flow velocity. **Subtask 4.4 Quantify CO_2 sequestered as residual gas saturation** – Simulate CO_2 tonnage sequestered as residual gas saturation due to counter-current flow between free-phase CO_2 (upwards) and aquifer brine (downwards). Also, understand effects of absolute and relative permeability, buoyancy, aquifer dip, background flow gradient, and alternating layers of aquifers and aquitards on residual trapping of CO_2. **Subtask 4.5. Quantify tonnage of CO_2 sequestrated by mineralization –** Conduct simulation over varying time scales (1000 to 10,000 yrs) using aquifer/aquitard-specific mineralogy and geochemistry to understand the availability of in situ metal oxides and impact of mineralization on porosity, location of maximum porosity change, effect of hydrodynamic flow, potential CO_2 tonnage locked permanently as minerals, and related time frames. **Subtask 4.6. Outline field management plans to maximize CO_2 entrapment –** Simulate scenarios such as simultaneous and sequential injection of CO_2 and brine from upper and lower zones respectively, use of horizontal CO_2 and brine injectors to model effects on plume development and incremental CO_2 sequestration, and estimate maximum injection rates that do not compromise cap rock integrity. **Subtask 4.7. Use Monte Carlo simulation estimate total CO_2 sequestration capacity** – Identify critical petrophysical parameters affecting CO_2 sequestration capacity using sensitivity studies, model related uncertainty stochastically using probability distributions based on facies-specific petrophysical database, and conduct Monte Carlo simulations to define P90/P10 values related to CO_2 sequestration volumes and injection rates. **Task 5: Conduct Simulation of CO_2-EOR Potential in Wellington Field** – The proposed study will simulate the potential for CO_2 sequestration and incremental oil recovery in Mississippian chat in the Wellington Field. **Subtask 5.1. Simulate CO_2-EOR potential of Wellington Field –** Primary and secondary production/injection data will be history matched to initialize the multi-layer (facies-based) geomodel. Simulate the water injection volume necessary to raise reservoir pressure above CO_2 miscibility, the effectiveness of typical 5-spot pattern (with central injector) for tertiary oil recovery, the tonnage of CO_2 sequestered, and ratio of produced CO_2 to incremental production. This will be followed by a full-field CO_2-EOR simulation (including WAG scenarios) to estimate total tonnage of CO_2 sequestered, incremental oil recovery, CO_2 recycling volumes, and identification of high injectivity zones. **Subtask 5.2. Evaluate long-term effectiveness of cap rock** – Use lab-measured capillary pressure data from overlying cap rock to simulate seal integrity (similar to that described in Subtask 4.2). **Subtask 5.3. Quantify CO_2 sequestered in brine solution** – Conduct studies similar to Subtask 4.3 using laboratory-measured facies-specific irreducible oil saturations to quantify tonnage of CO^2 sequestered in Wellington Field at end of EOR. **Subtask 5.4. Evaluate potential of CO_2 sequestration by mineralization** – Model mineralization reactions using reservoir brine chemistry and facies-specific mineralogy to estimate tonnage of CO_2 permanently trapped as minerals (follow Subtask 4.4). **Subtask 5.5. Outline field management plans to optimize oil recovery by CO_2-EOR** – Simulation studies will be conducted to outline the optimum injection-production pattern in the Wellington Field to maximize tertiary recovery, delay CO_2 breakthrough, estimate produced CO_2 volumes (for recycling), and total amount of CO_2 sequestered in the reservoir before produced GOR becomes uneconomic. **Subtask 5.6. Estimate total CO_2 sequestration capacity and EOR in Wellington Field using Monte Carlo simulation** – Following Subtask 4.6, Monte Carlo simulations will quantify uncertainty related to total volumes of CO_2 sequestered and oil recovered. **PHASE IV** – **Task 6: Characterization of potential leakage pathways in risk assessment area** – Faults/fractures and wells in and around the Wellington Field are potential leakage pathways, and so the risk assessment area, 10 miles outside the boundary of the field, will be analyzed in detail.[53] **Subtask 6.1. Assemble available 3D data** – Discussions with operators working in the risk assessment area have elicited positive responses regarding sharing of 3D seismic and well completion data with KGS. **Subtask 6.2. Map fracture-fault network** – Available 3D seismic data will be analyzed to map faults/fractures within the risk assessment area and to define open and closed fractured networks. **Subtask: 6.3. Verify seal continuity and integrity –** Primary and secondary seals in the risk assessment area will be mapped for continuity and thickness. Data from core analysis, petrography, isotope and fluid inclusion analyses, sequence stratigraphic studies, and wireline log analysis will be integrated to map cemented impermeable zones, thick widespread marine shales, and anhydrite – all barrier zones overlying portions of the 17+ -county regional study area. **Subtask 6.4. Inventory well status** – Inventory completion and abandonment history of all wells in risk assessment area using records from the Kansas Corporation Commission, KGS, and respective oil and gas operators. **Subtask 6.5. Gather expert-advice on well integrity** – Expert advice, related to practical permeability ranges for cement and abandonment plugs, based on age and condition of the wells, will be sought to quantify current and long-term mechanical well-integrity. **Task 7: Risk Assessment Related to CO_2-EOR in Mississippian Chat Reservoir and CO_2 Sequestration in Arbuckle Aquifers** – Subsurface pressure remains high during CO_2 injection and then declines to equilibration after injection stops, so near- and long-term leakage scenarios will be simulated. **Subtask 7.1. Model CO_2 plume for 100, 1000, and 5000 yrs after injection stops** – As the plume spreads in the aquifer/reservoir, it contacts fresh brine for additional dissolution, mineralization, and eventual entrapment as residual gas saturation. Assuming 25-years of injection, the free-phase CO_2 plume will be simulated for up to 5000 years to verify containment within risk assessment area, to determine if CO_2 plume will transition from super- to sub-critical conditions, and determine the effect of low-permeability anisotropic layers in diverting upward movement of the plume. **Subtask 7.2. Model plume movement if intersected by fault** – If simulation shows that the CO_2 plume may come close to faults mapped in the risk assessment area, scenarios will be simulated to understand how free CO_2 behaves upon encountering sealing or conductive faults with varying geometries and connections to permeable zones. **Subtask 7.3. Model plume attenuation during and after injection** – The Arbuckle Group is made up of alternating aquifer and aquitards with different petrophysical properties. Low permeability aquitards with relatively higher residual gas saturations will result in greater CO_2 entrapment. Scenarios will be simulated to quantify free CO_2 accumulation under the cap rock with CO_2 injected in the deepest high permeability aquifer to force free CO_2 travel through a succession of aquitards and aquifers before reaching the cap rock. **Subtask 7.4. Model effects of natural aquifer flow on CO_2 plume** – Scenarios will be simulated to study the sensitivity of plume dispersion to background aquifer velocity and prevalent direction of flow. **Subtask 7.5. Estimate time frame for free phase CO_2 to become negligible** – Free-phase CO_2 poses the biggest risk in terms of leakage. Run coarse-grid simulations for 10,000+ years to determine the time necessary to sequester all injected CO_2 into solution, residual gas saturation, and minerals. **Subtask 7.6. Model effectiveness of cap rocks to contain leakage** – Simulate different injection rates to estimate the maximum pressure increase under the cap rock for comparison with laboratory-measured yield points of respective cap rocks of Mississippian reservoir and Arbuckle aquifer. **Subtask 7.7. Leakage modeling through abandoned wells** – Well leakage will be simulated using the FEHM simulator[36] (Los Alamos National Laboratory), a non-isothermal, multi-phase simulator used for risk analysis in CO_2 sequestration, which uses pressure and phase saturation distributions (from conventional composition simulators such as CMG-GEM) and hybrid grids to explicitly model well completion and abandonment details such as the location of annulus cement, abandonment plugs, and their inferred permeabilities. Wells in risk assessment area will be grouped as: a) drilled and abandoned, b) cased and abandoned, and c) cased and producing. Three permeabilities (high, medium, and low) will be assigned to cement and plugs based on expert inputs. A multi-layer reservoir model (including aquifers and aquitards) will be constructed in FEHM to simulate the tonnage of CO_2 (as a fraction of injection) expected to leak through existing wells. **Subtask 7.8. Model worst-case CO_2 leakage scenario –** Worst case leakage (as fraction of injected volumes leaked) will be identified by simulating (in FEHM) scenarios that assume that 25, 50, and 100% of the wells, grouped in descending order of their age, suffer from cement failures simultaneously at different times: a) early in injection (5th year), b) mid-way through injection (12th year), c) end of injection (25th yr), and d) after 50th year after the start of injection. **Subtask 7.9. Estimate shallow environmental effects due to leakage** – Based on worst-case leakage (Subtask 7.8), the CO_2 leakage flux will be distributed over one acre (as result of wind dispersion) to estimate if surface concentration of CO_2 is injurious to health. The Wellington Field is located in the rural Kansas with low risk of CO_2 leaking into a home. **Task 8: Produced Water and Wellbore Management Plans – Subtask 8.1. Identify at-risk wells in Wellington Field** – The FEHM simulator study will identify wells that have high leakage potential due to failure of mechanical integrity. **Subtask 8.2. Outline Best Practices and well recompletion plans for at-risk wells –** Best practices to recomplete at-risk wells will be outlined based on inputs from well completion expert, K. Cooper. **Subtask 8.3. Outline Best practices and well completion plans for new CO_2 injector wells** – Best practices and well completion plans related to CO_2 injector in the Wellington Field will be summarized by K. Cooper (Subtask 8.2). **Subtask 8.4. Summarize practices in place for disposal of produced water** – Infrastructure for disposal of produced water is currently in place in the Wellington Field. Current disposal practices will be summarized. **Task 9: Regional CO_2 Sequestration Potential in the OPAS in 17+ -Counties in**

South-Central Kansas – Regional CO_2 sequestration potential will be evaluated, by reservoir simulation of prospective areas in the Arbuckle Group. **Subtask 9.1. Map reservoir compartments in Arbuckle aquifer in a regional context –** 3D seismic data from the multi-county area, donated by operators, will be analyzed with well data and publicly available air photos, satellite imagery, and gravity and magnetic data. Major faults and fractures will be delineated. Major Arbuckle compartments will be identified and characterized. **Subtask 9.2. Coarse grid simulation over select OPAS areas to estimate regional CO_2 sequestration potential** – Coarse-grid reservoir simulation studies will be conducted with CMG-GEM on select major Arbuckle compartments to evaluate their sequestration potential using lithofacies-based petrophysical properties. Important considerations include prevention of the CO_2 plume from breaching cap rock and reaching nearby fault and fracture networks. Simultaneous brine injection from upper zones will be simulated to test for maximum CO_2 sequestration. **Subtask 9.3. Generalized estimates of miscible CO_2-EOR in similar and larger oil fields in 17+-counties** – This study will identify major fields that meet the requirements for successful CO_2-EOR including the following parameters: primary production volumes, success of secondary recovery, estimated MMP (based on oil gravity), isolation from underlying aquifer, average depth to attain miscibility, and leakage issues related to old wells. Lessons learned (i.e., ratio of tertiary recovery to total production, volume of CO_2 sequestered, and volume of CO_2 recycled per barrel of tertiary recovery) from modeling of CO_2-EOR in the Wellington Field will be used to estimate incremental oil recovery potential from nearby major oil fields. **Subtask 9.4. Estimate regional CO_2 sequestration potential of OPAS –** Results from the above 3 subtasks will be integrated to estimate the total CO_2 sequestration. **Task 10: Regional Source-Sink Relationships in 17+-Counties in South-Central Kansas – Subtask 10.1. Map major point CO_2 sources in Kansas** – Emission details of major point sources of CO_2 in Kansas will be extracted from the NatCarb database, and displayed on project website. **Subtask 10.2. Map major CO_2 sinks in Kansas –** Maps will be generated to display depleted oil fields with maximum CO_2-EOR potential and Arbuckle aquifer compartments. **Task 11: Technology Transfer – Subtask 11.1 Build and maintain project website** – The project website will be hosted by the KGS and will be regularly updated with pertinent project results and progress. Many results will be accessible through interactive map and web-based tools (Subtask 2.2) **Subtask 11.2. Conduct CO_2 sequestration and core workshops** – Topical results and lessons learned on geology, engineering, and geophysics will be presented in workshops to the oil and gas industry and other interested parties. **Subtask 11.3. Present project results at various professional meetings and technical forum** – Project results will be published as posters and oral presentations in professional meetings and technical forums, including DOE-sponsored meetings. **Subtask 11.4 Publish project results in peer reviewed journals** – Various aspects of the project will be summarized and submitted as articles in relevant peer-reviewed technical journals. **Subtask 11.5 Write quarterly and annual progress to DOE** – The KGS will submit all necessary reports to DOE. It will also present project results and status to DOE upon request, and will follow-up with all necessary paperwork as required by DOE.

D. DELIVERABLES – **Phase I** – Task 1 – project management plan and reporting on activities. Task 2 – initial characterization of OPAS. Task 3 – geomodel of the reservoir and aquifer in the Wellington Field. **Phase II** – Tasks 4 & 5 – simulations of the Arbuckle aquifer and Mississippian chat reservoir in the Wellington Field. **Phases III** – Task 6 – characterization of possible leakage pathways. Task 7 – risk assessment. Task 8 – plan for produced water and wellbore management. Task 9 – final geomodel and simulation of regional CO_2 sequestration potential. **Phase IV** – Task 10 – regional source-sink relationships. Task 11 – technology transfer component including project website, workshops, presentations at meetings, publications in peer-reviewed journals, and periodic, topical, and final reports that shall be submitted in accordance with the attached "Federal Assistance Reporting Checklist" and the checklist.

E. BRIEFINGS/TECHNICAL PRESENTATIONS – Briefings will be presented to the Project Officer at the Project Officer's facility (Pittsburgh or Morgantown) to explain the plans, progress, and results. Presentation will be made to the NETL Project Officer/Manager at a project kick-off meeting, annual briefings, and a final project briefing. Technical papers will be presented at the DOE/NETL Annual Contractor's Review Meeting to be held at the NETL facility located in Pittsburgh, PA or Morgantown, WV, and at least one other technical conference each year, as approved by the NETL Project Officer/Manager. The Recipient will hold an open house event at their project site by June 2011.